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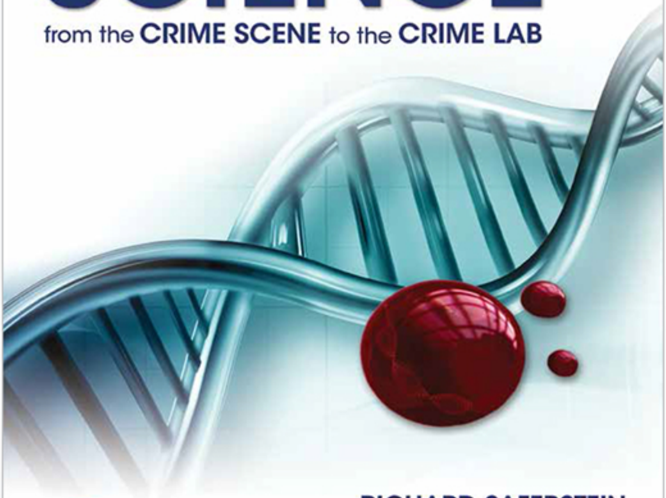
Fourth Edition

FORENSIC SCIENCE

from the CRIME SCENE to the CRIME LAB



RICHARD SAFERSTEIN

FORENSIC SCIENCE

Fourth Edition

From the CRIME SCENE to the CRIME LAB

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For Mom (1917–2010)

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The Washington Post
The New York

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PREFACE

New to This Edition

- ***New!*** Numerous case files have been added to select chapters to illustrate how forensic technology has been applied to solving crimes of notoriety.
- Chapter 3, "Recording the Crime Scene," has been updated to include a discussion of body worn cameras and their role in crime scene documentation.
- Chapter 8, "Forensic Biometrics: Fingerprints and Facial Recognition," is a new chapter focusing on the application of fingerprint, iris, and facial biometrics used to create biometric databases.
- Chapter 5, "Physical Evidence," has been updated to introduce the reader to the new FBI Next Generation Identification system (NGI), created as a repository for biometric information.
- Chapter 15, "DNA: The Indispensable Tool," has been revised to address updates to the Combined DNA Indexing System to reflect newly implemented technologies and database expansion.
- Chapter 16, "Forensic Aspects of Fire and Explosion Investigation," has been expanded to cover the discussion of the deviation of fire from normal behavior and how it impacts on burn pattern interpretations at fire scenes.
- Information throughout the text has been updated and many new figures have been added to illustrate concepts discussed in the chapters.

Purpose of This Book

When one sets out to write a textbook on the current state of forensic science, the first things that come to mind are all the sophisticated high-tech devices at the disposal of the forensic analyst. A textbook devoted to this topic can quickly overwhelm the student who has little or no prior coursework in the basic sciences and who is averse to correcting this deficiency. Although a study of forensic science must include coverage of some basic scientific principles, the coverage must be presented in a fashion that will not "turn off" the student. Like the third edition, *Forensic Science: From the Crime Scene to the Crime Lab*, Fourth Edition, is designed to accomplish this objective by presenting the science of forensics in a straightforward and student-friendly format.

Topics are arranged to integrate scientific methodology with actual forensic applications. Discussions of the scientific topics focus on state-of-the-art technology without delving into extraneous theories that may bore or overwhelm the nonscience student. Only the most relevant scientific and technological concepts are presented. A major portion of the text centers on the role of the crime-scene investigator in preserving, recording, and collecting physical evidence at the crime scene. Chapter 3, describing the application of photography to the crime scene, has been updated to introduce the use of the body worn camera at crime scenes. One key concern during the collection of a DNA-containing specimen is contamination. Appropriate insights have been added to the text for minimizing this type of occurrence during the collection and packaging of biological evidence. The fourth edition also includes a new chapter (Chapter 8), "Forensic Biometrics and Facial Recognition."

Descriptions and pertinent forensic facts about cases of notoriety are provided for the reader. The intent is to demonstrate to the reader actual applications of forensic science to real-life case investigations.

The reader is offered the option of delving into the more difficult technical aspects of the subject by reading the Closer Analysis features. This option can be bypassed without detracting from a basic comprehension of the subject of forensic science.

Within and at the end of each chapter, the reader will encounter Quick Reviews and a Chapter Review that recap all of the major points of the chapter. The end-of-chapter Summary is followed by Review Questions, as well as Application and Critical Thinking exercises designed to enhance the reader's learning experience.

Acknowledgments

I would like to thank Tiffany Roy for her assistance in the preparation of the newest edition of this book. Tiffany is a Forensic DNA expert living and working in South Florida, who has worked in both public and private DNA laboratories in the United States. As an undergraduate professor and a licensed attorney, her unique perspective influenced a number of chapter updates as well as case file additions.

I am most appreciative of the contribution that retired Lieutenant Andrew (Drew) Donofrio of New Jersey's Bergen County Prosecutor's Office and now a leading private computer forensic examiner made to this new edition. I was fortunate to find in Drew a contributor who not only possesses extraordinary skill, knowledge, and hands-on experience with computer forensics, but was able to combine those attributes with sophisticated communication skills. Likewise, I was fortunate to have Dr. Peter Stephenson contribute to this book on the subject of mobile forensics. He brings skills as a cybercriminologist, author, and educator in digital forensics.

Likewise, I was very fortunate to engage the services of Michelle Tetrault as my research assistant during the preparation of the first and second editions of *Forensic Science: From the Crime Scene to the Crime Lab*. Michelle is an extraordinarily gifted student out of Cedar Crest College in Allentown, Pennsylvania, and George Washington University. She was instrumental in helping me write and organize a number of the chapters in this text. Her skills and tenacity in carrying out her tasks are acknowledged and greatly appreciated.

Likewise, Jacque Campbell, a graduate student in forensic science from Arcadia University, provided valuable assistance in preparing chapter updates and examination questions for the new edition.

Many people provided assistance and advice in the preparation of this book. Many faculty members, colleagues, and friends have read and commented on various portions of the text. I would like to acknowledge the contributions of Anita Wonder, Robert J. Phillips, Norman H. Reeves, Jeffrey C. Kercheval, Robert Thompson, Roger Ely, Jose R. Almirall, Michael Malone, Ronald Welsh, Joshua Wilborne, David Pauly, Jan Johnson, Natalie Borgan, Dr. Barbara Needell, Robin D. Williams, Peter Diaczuk, Ken Radwill, Randi Dubnick, and Jacqueline E. Joseph. I'm appreciative of the contributions, reviews, and comments that Dr. Claus Speth, Dr. Mark Taff, Dr. Elizabeth Laposata, Thomas P. Mauriello, and Michelle D. Miranda provided during the preparation of Chapter 6, "Death Investigation."

Finally, I thank the following reviewers of this edition: Vicki Harder, Western New Mexico University, Becky Merrow, White Mountains Community College Jerry Stinson II, Southwest Virginia Community College, Kelly Treece, Glenville State College.

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REVEL for *Forensic Science: From the Crime Scene to the Crime Lab,* Fourth Edition by Richard Saferstein

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ABOUT THE AUTHOR

RICHARD SAFERSTEIN, Ph.D., retired in 1991 after serving for twenty-one years as the chief forensic scientist of the New Jersey State Police Laboratory, one of the largest crime laboratories in the United States. He currently acts as a consultant for attorneys and the media in the area of forensic science. During the O. J. Simpson criminal trial, Dr. Saferstein provided extensive commentary on forensic aspects of the case for the *Rivera Live* show, the E! television network, ABC radio, and various radio talk shows. Dr. Saferstein holds degrees from the City College of New York and earned his doctorate degree in chemistry in 1970 from the City University of New York. From 1972 to 1991, he taught an introductory forensic science course in the criminal justice programs at the College of New Jersey and Ocean County College. These teaching experiences played an influential role in Dr. Saferstein's authorship in 1977 of the widely used introductory textbook *Criminalistics: An Introduction to Forensic Science,* currently in its twelfth edition. Dr. Saferstein's basic philosophy in writing *Forensic Science: From the Crime Scene to the Crime Lab*, Fourth Edition, is to make forensic science understandable and meaningful to the nonscience reader while giving the reader an appreciation for the scientific principles that underlie the subject.

Dr. Saferstein has authored or coauthored more than forty-five technical papers covering a variety of forensic topics. He authored *Basic Laboratory Exercises for Forensic Science,* Second Edition (Prentice Hall, 2011), and coauthored *Lab Manual for Criminalistics*, Eleventh Edition (Prentice Hall, 2015). He has also edited the widely used professional reference books *Forensic Science Handbook*, Volume 1, Second Edition (Prentice Hall, 2002), *Forensic Science Handbook*, Volume 2, Second Edition (Prentice Hall, 2005), and *Forensic Science Handbook*, Volume 3, Second Edition (Prentice Hall, 2010). Dr. Saferstein is a member of the American Chemical Society, American Academy of Forensic Sciences, Canadian Society of Forensic Scientists, International Association for Identification, Northeastern Association of Forensic Scientists, and Society of Forensic Toxicologists.

In 2006, Dr. Saferstein received the American Academy of Forensic Sciences Paul L. Kirk award for distinguished service and contributions to the field of criminalistics.

TIFFANY ROY, JD, made substantial contributions assisting Dr. Saferstein in the revision of this edition of the textbook, the supplements that accompany the textbook, and the new Revel interactive etext. Roy is a Forensic DNA expert with over eleven years of forensic biology experience in both public and private laboratories in the United States. She instructs undergraduates at Palm Beach Atlantic University in West Palm Beach, Florida; University of Maryland University College; and Southern New Hampshire University. She currently acts as a consultant for attorneys and the media in the area of forensic biology through her firm, *ForensicAid, LLC*. Roy holds degrees from Syracuse University, Massachusetts School of Law, and University of Florida in the areas of Biology, Law, and Forensic Science. Her teaching, legal writing, and testimonial experience help her to take complex scientific concepts and make them easily understandable for the nonscientist.

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1 Introduction

Red Huber-Pool/Getty Images

LEARNING OBJECTIVES

After studying this chapter, you should be able to:

- Distinguish between forensic science and criminalistics.
- Outline the main historical developments of forensic science.
- Describe the organization and services of a typical comprehensive crime laboratory in the criminal justice system.
- Understand what specialized forensic services, aside from the crime laboratory, are generally available to law enforcement personnel.
- Explain how physical evidence is analyzed and presented in the courtroom by the forensic scientist, and how admissibility of evidence is determined in the courtroom.

Go to www.pearsonhighered.com/careersresources to access Webextras for this chapter.

CASEY ANTHONY: THE CSI EFFECT?

Few criminal proceedings have captured the attention of the American public or have invoked stronger emotions than the Casey Anthony murder trial. How could a defendant who failed to report her two-year-old child missing for thirty-one days walk away scot-free from a murder conviction? This case had all the makings of a strong circumstantial case for the state.

The state's theory was that Casey used chloroform to render her daughter unconscious, placed duct tape over Caylee's mouth and nose, and kept the body in the trunk for several days before disposing of it. Caylee's decomposed remains were discovered more than five months after she was reported missing.

Have TV forensic dramas created an environment in the courtroom that necessitates the existence of physical evidence to directly link a defendant to a crime scene? The closest the state came to a direct link was a hair found in the trunk of Casey's car. However, the DNA test on the hair could link the hair only to Caylee's maternal relatives: Casey, Casey's mother (Caylee's maternal grandmother), and Casey's brother (Caylee's uncle). And Caylee herself. No unique characteristics were found to link the duct tape on the body with that found in the Anthony home.

No DNA, no fingerprints, no conviction.

Definition and Scope of Forensic Science

Forensic science, in its broadest definition, is the application of science to law. As our society has grown more complex, it has become more dependent on rules of law to regulate the activities of its members. Forensic science applies the knowledge and technology of science to the definition and enforcement of such laws.

Each year, as government finds it increasingly necessary to regulate the activities that most intimately influence our daily lives, science merges more closely with civil and criminal law. Consider, for example, the laws and agencies that regulate the quality of our food, the nature and potency of drugs, the extent of automobile emissions, the kind of fuel oil we burn, the purity of our drinking water, and the pesticides we use on our crops and plants. It would be difficult to conceive of a food or drug regulation or environmental protection act that could be effectively monitored and enforced without the assistance of scientific technology and the skill of the scientific community.

Laws are continually being broadened and revised to counter the alarming increase in crime rates. In response to public concern, law enforcement agencies have expanded their patrol and investigative functions, hoping to stem the rising tide of crime. At the same time, they are looking more to the scientific community for advice and technical support for their efforts. Can the technology that put astronauts on the moon, split the atom, and eradicated most dreaded diseases be enlisted in this critical battle?

Unfortunately, science cannot offer final and authoritative solutions to problems that stem from a maze of social and psychological factors. However, as the content of this book attests, science occupies an important and unique role in the criminal justice system—a role that relates to the scientist's ability to supply accurate and objective information about the events that have occurred at a crime scene. A good deal of work remains to be done if the full potential of science as applied to criminal investigations is to be realized.

Because of the vast array of civil and criminal laws that regulate society, forensic science, in its broadest sense, has become so comprehensive a subject that a meaningful introductory textbook treating its role and techniques would be difficult to create and probably overwhelming to read. For this reason, we have narrowed the scope of the subject according to the most common definition: **Forensic science is the application of science to the criminal and civil laws that are enforced by police agencies in a criminal justice system.** "Forensic science" is an umbrella term encompassing a myriad of professions that use their skills to aid law enforcement officials in conducting their investigations.

The diversity of professions practicing forensic science is illustrated by the eleven sections of the American Academy of Forensic Sciences, the largest forensic science organization in the world:

1. Criminalistics
2. Digital and Multimedia Sciences
3. Engineering Science
4. General
5. Jurisprudence
6. Odontology
7. Pathology/Biology
8. Physical Anthropology
9. Psychiatry/Behavioral Science
10. Questioned Documents
11. Toxicology

Even this list of professions is not exclusive. It does not encompass skills such as fingerprint examination, firearm and tool mark examination, and photography.

Obviously, to author a book covering all of the major activities of forensic science as they apply to the enforcement of criminal and civil laws by police agencies would be a major undertaking. Thus, this book will further restrict itself to discussions of the subjects of chemistry, biology, physics, geology, and computer technology, which are useful for determining the evidential value of crime-scene and related evidence. Forensic pathology, psychology, anthropology, and odontology also encompass important and relevant areas of knowledge and practice in law enforcement, each being an integral part of the total forensic science service that is provided to any up-to-date criminal justice system. However, these subjects go beyond the intended scope of this book, and except for brief discussions, along with pointing the reader to relevant websites, the reader is referred elsewhere for discussions of their applications and techniques. Instead, this book focuses on the services of what has popularly become known as the crime laboratory, where the principles and techniques of the physical and natural sciences are practiced and applied to the analysis of crime-scene evidence.

For many, the term "criminalistics" seems more descriptive than "forensic science" for describing the services of a crime laboratory. Regardless of his or her title—"criminalist" or "forensic scientist"—the trend of events has made the scientist in the crime laboratory an active participant in the criminal justice system.

Prime-time television shows like *CSI: Crime Scene Investigation* have greatly increased the public's awareness of the use of science in criminal and civil investigations (see Figure 1-1). However, by simplifying scientific procedures to fit the allotted airtime, these shows have created within both the public and the legal community, unrealistic expectations of forensic science. In these shows, members of the CSI team collect evidence at the crime scene, process all evidence, question witnesses, interrogate suspects, carry out search warrants, and testify in court. In the real world, these tasks are almost always

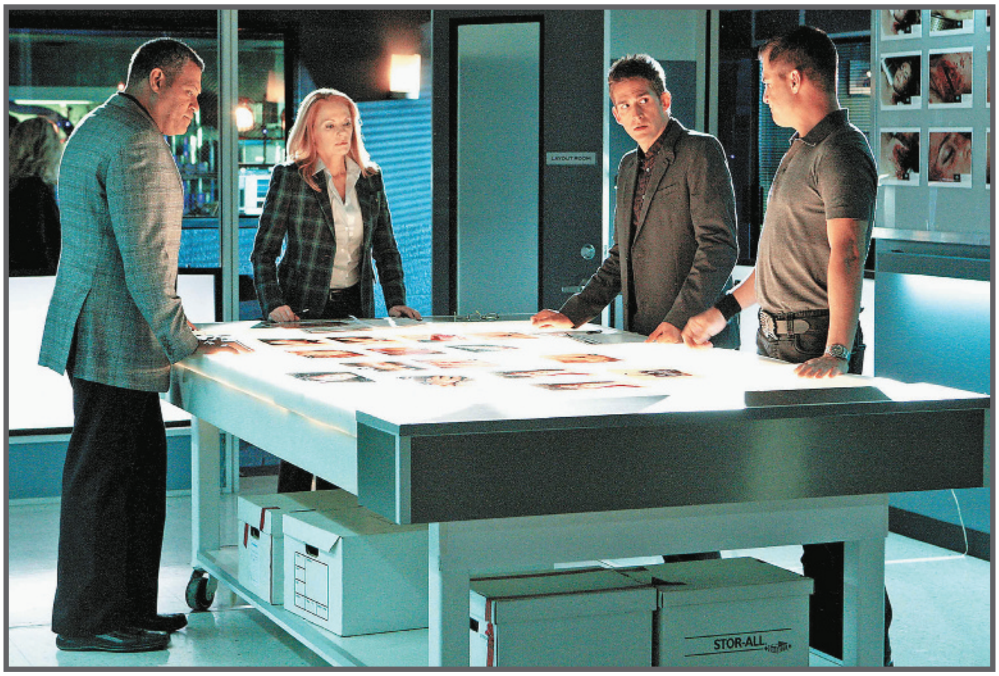

FIGURE 1-1 A scene from *CSI*, a forensic science television show. *SUN/Newscom*

delegated to different people in different parts of the criminal justice system. Procedures that in reality could take days, weeks, months, or years appear on these shows to take mere minutes. This false image is significantly responsible for the public's high interest in and expectations for DNA evidence.

The dramatization of forensic science on television has led the public to believe that every crime scene will yield forensic evidence, and it produces unrealistic expectations that a prosecutor's case should always be bolstered and supported by forensic evidence. This phenomenon is known as the "CSI effect." Some jurists believe that this phenomenon ultimately detracts from the search for truth and justice in the courtroom.

History and Development of Forensic Science

Forensic science owes its origins, first, to the individuals who developed the principles and techniques needed to identify or compare physical evidence and, second, to those who recognized the need to merge these principles into a coherent discipline that could be practically applied to a criminal justice system.

The roots of forensic science reach back many centuries, and history records a number of instances in which individuals closely observed evidence and applied basic scientific principles to solve crimes. Not until relatively recently, however, did forensic science take on the more careful and systematic approach that characterizes the modern discipline.

EARLY DEVELOPMENTS

One of the earliest records of applying forensics to solve criminal cases comes from third-century China. A manuscript titled *Yi Yu Ji* ("A Collection of Criminal Cases") reports how a coroner solved a case in which a woman was suspected of murdering her husband and burning the body, claiming that he died in an accidental fire. Noticing that the husband's corpse had no ashes in its mouth, the coroner performed an experiment to test the woman's story. He burned two pigs—one alive and one dead—and then checked for ashes inside the mouth of each. He found ashes in the mouth of the pig that was alive before it was burned, but none in the mouth of the pig that was dead beforehand. The coroner thus concluded that the husband, too, was dead before his body was burned. Confronted with this evidence, the woman admitted her guilt. The Chinese were also among the first to recognize the potential of fingerprints as a means of identification.

Although cases such as that of the Chinese coroner are noteworthy, this kind of scientific approach to criminal investigation was for many years the exception rather than the rule. Limited knowledge of anatomy and pathology hampered the development of forensic science until the late seventeenth and early eighteenth centuries. For example, the first recorded notes about fingerprint characteristics were prepared in 1686 by Marcello Malpighi, a professor of anatomy at the University of Bologna in Italy. Malpighi, however, did not acknowledge the value of fingerprints as a method of identification. The first scientific paper about the nature of fingerprints did not appear until more than a century later, but it also did not recognize their potential as a form of identification.

INITIAL SCIENTIFIC ADVANCES

As physicians gained a greater understanding of the workings of the body, the first scientific treatises on forensic science began to appear, such as the 1798 work "A Treatise on Forensic Medicine and Public Health" by the French physician François-Emanuel Fodéré. Breakthroughs in chemistry at this time also helped forensic science take significant strides forward. In 1775, the Swedish chemist Carl Wilhelm Scheele devised the first successful test for detecting the poison arsenic in corpses. By 1806, the German chemist Valentin Ross had discovered a more precise method for detecting small amounts of arsenic in the walls of a victim's stomach. The most significant early figure in this area was Mathieu Orfila (see Figure 1-2), a Spaniard who is considered the father of forensic toxicology. In 1814, Orfila published the first scientific treatise on the detection of poisons and their effects on animals. This treatise established forensic toxicology as a legitimate scientific endeavor.

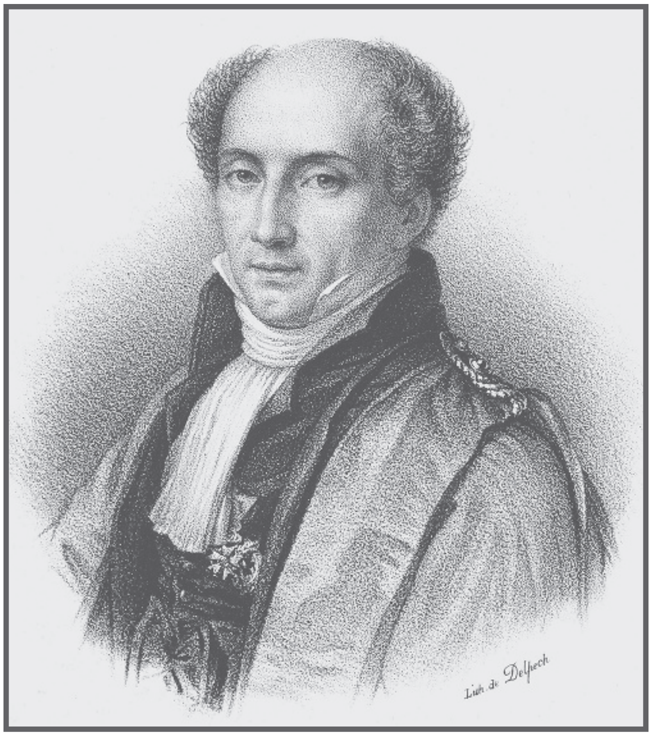

FIGURE 1-2 Mathieu Orfila.
Matthieu Orfila/The Granger Collection

The mid-1800s saw a spate of advances in several scientific disciplines that furthered the field of forensic science. In 1828, William Nichol invented the polarizing microscope. Eleven years later, Henri-Louis Bayard formulated the first procedures for microscopic detection of sperm. Other developments during this time included the first microcrystalline test for hemoglobin (1853) and the first presumptive test for blood (1863). Such tests soon found practical applications in criminal trials. Toxicological evidence at trial was first used in 1839, when a Scottish chemist named James Marsh testified that he had detected arsenic in a victim's body. During the 1850s and 1860s, the new science of photography was also used in forensics to record images of prisoners and crime scenes.

LATE-NINETEENTH-CENTURY PROGRESS

By the late nineteenth century, public officials were beginning to apply knowledge from virtually all scientific disciplines to the study of crime. Anthropology and morphology (the study of the structure of living organisms) were applied to the first system of personal identification, devised by the French scientist Alphonse Bertillon in 1879. Bertillon's system, which he dubbed "anthropometry," was a procedure that involved taking a series of bodily measurements as a means of distinguishing one individual from another (see Figure 1-3). For nearly two decades, this system was considered the most accurate method of personal identification. Bertillon's early efforts earned him the distinction of being known as the "father of criminal identification."

Bertillon's anthropometry, however, would soon be supplanted by a more reliable method of identification: fingerprinting. Two years before the publication of Bertillon's system, U.S. microscopist Thomas Taylor had suggested that fingerprints could be used as a means of identification, but his ideas were not immediately followed up. Three years later, the Scottish physician Henry Faulds made a similar assertion in a paper published in the journal *Nature*. However, it was the Englishman Francis Henry Galton who undertook the first definitive study of fingerprints and developed a methodology of classifying them for filing. In 1892, Galton published a book titled *Finger Prints* that contained the first statistical proof supporting the uniqueness of fingerprints and the effectiveness of his method. His book went on to describe the basic principles that would form our present system of identification by fingerprints.

The first treatise describing the application of scientific disciplines to the field of criminal investigation was written by Hans Gross in 1893. Gross,

FIGURE 1-3 Bertillon's system of bodily measurements used for the identification of an individual. *Sirchie Finger Print Laboratories, Youngsville, NC, www.sirchie.com*

a public prosecutor and judge in Graz, Austria, spent many years studying and developing principles of criminal investigation. In his classic book *Handbuch für Untersuchungsrichter als System der Kriminalistik* (later published in English under the title *Criminal Investigation*), he detailed the assistance that investigators could expect from the fields of microscopy, chemistry, physics, mineralogy, zoology, botany, anthropometry, and fingerprinting. He later introduced the forensic journal *Archiv für Kriminal Anthropologie und Kriminalistik,* which still reports improved methods of scientific crime detection.

Ironically, the best-known figure in nineteenth-century forensics is not a real person but a fictional character: the legendary detective Sherlock Holmes (see Figure 1-4). Many people today believe that Holmes's creator, Sir Arthur Conan Doyle, had a considerable influence on popularizing scientific crime-detection methods. In adventures with his partner and biographer, Dr. John Watson, Holmes was the first to apply the newly developing principles of serology (the study of blood and bodily fluids), fingerprinting, firearms identification, and questioned-document examination long before their value was recognized and accepted by real-life criminal investigators. Holmes's feats excited the imagination of an emerging generation of forensic scientists and criminal investigators. Even in the first Sherlock Holmes novel, *A Study in Scarlet,* published in 1887, we find examples of Doyle's uncanny ability to describe scientific methods of detection years before they were actually discovered and implemented. For instance, here Holmes explains the potential usefulness of forensic serology to criminal investigation:

FIGURE 1-4 Sir Arthur Conan Doyle's legendary detective Sherlock Holmes applied many of the principles of modern forensic science long before they were adopted widely by real-life police. *Ostill/Shutterstock*

> "I've found it. I've found it," he shouted to my companion, running toward us with a test tube in his hand. "I have found a reagent which is precipitated by hemoglobin and by nothing else. . . . Why, man, it is the most practical medico-legal discovery for years. Don't you see that it gives us an infallible test for bloodstains? . . . The old guaiacum test was very clumsy and uncertain. So is the microscopic examination for blood corpuscles. The latter is valueless if the stains are a few hours old. Now, this appears to act as well whether the blood is old or new. Had this test been invented, there are hundreds of men now walking the earth who would long ago have paid the penalty of their crimes. . . . Criminal cases are continually hinging upon that one point. A man is suspected of a crime months perhaps after it has been committed. His linen or clothes are examined and brownish stains discovered upon them. Are they bloodstains, or rust stains, or fruit stains, or what are they? That is a question which has puzzled many an expert, and why? Because there was no reliable test. Now we have the Sherlock Holmes test, and there will no longer be any difficulty."

TWENTIETH-CENTURY BREAKTHROUGHS

The pace of technological change quickened considerably in the twentieth century, and with it the rate of advancements in forensic science. In 1901, Dr. Karl Landsteiner discovered that blood can be grouped into different categories, now recognized as the blood types A, B, AB, and O. The possibility that blood grouping could be useful in identifying an individual intrigued Dr. Leone Lattes, a professor at the Institute of Forensic Medicine at the University of Turin in Italy. In 1915, Lattes devised a relatively simple procedure for determining the blood group of the dried blood in a bloodstain, a technique that he immediately applied to criminal investigations.

At around the same time, Albert S. Osborn was conducting pioneering work in document examination. In 1910, Osborn wrote the first significant text in this field, *Questioned Documents*. This book is still a primary reference for document examiners. Osborn's development of fundamental principles of document examination was responsible for the acceptance of documents as scientific evidence by the courts.

One of the most important contributors to the field in the early twentieth century was the Frenchman Edmond Locard (see Figure 1-5). Although Hans Gross was a pioneering advocate for the use of the scientific method in criminal investigations, Locard first demonstrated how the principles enunciated by Gross could be incorporated within a workable crime laboratory. Locard's formal education was in both medicine and law. In 1910, he persuaded the Lyons Police Department to give him two attic rooms and two assistants to start a police laboratory. During Locard's first years of work, the instruments available to him were a microscope and a rudimentary spectrometer. However, his enthusiasm quickly overcame the technical and budgetary deficiencies he encountered, and from these modest beginnings, Locard conducted research and made discoveries that became known throughout the world by forensic scientists and criminal investigators. Eventually he became the founder and director of the Institute of Criminalistics at the University of Lyons, which quickly developed into a leading international center for study and research in forensic science.

Locard's exchange principle
Whenever two objects come into contact with one another, materials are exchanged between them.

Locard asserted that when two objects come into contact with each other a cross-transfer of materials occurs (**Locard's exchange principle**). He strongly believed that every criminal can be connected to a crime by dust particles carried from the crime scene. This concept was reinforced by a series of successful and well-publicized investigations. In one case, presented with counterfeit coins and the names of three suspects, Locard urged the police to bring the suspects' clothing to his laboratory. On careful examination, he located small metallic particles in all the garments. Chemical analysis revealed that the particles and coins were composed of exactly the same metallic elements. Confronted with this evidence, the suspects were arrested and soon confessed to the crime. After World War I, Locard's successes inspired the formation of police laboratories in Vienna, Berlin, Sweden, Finland, and Holland.

The microscope came into widespread use in forensic science during the twentieth century, and its applications grew dramatically. Perhaps the leading figure in the field of microscopy was Dr. Walter C. McCrone. During his lifetime, McCrone became the world's preeminent microscopist. Through his books, journal publications, and research institute, he was a tireless advocate for applying microscopy to analytical problems, particularly forensic science cases. McCrone's exceptional communication skills made him a much-sought-after instructor, and he educated thousands of forensic scientists throughout the world in the application of microscopic techniques. Dr. McCrone used microscopy, often in conjunction with other analytical methodologies, to examine evidence in thousands of criminal and civil cases throughout his long and illustrious career.

Another trailblazer in forensic applications of microscopy was U.S. Army Colonel Calvin Goddard, who refined the techniques of firearms examination by using the comparison microscope. Goddard's work allows investigators to determine whether a particular gun has fired a bullet by comparing the bullet with another that is test-fired from the suspect's weapon. From the mid-1920s on, his expertise established the comparison microscope as the indispensable tool of the modern firearms examiner.

FIGURE 1-5 Edmond Locard. *Roger Viollet/The Image Works*

MODERN SCIENTIFIC ADVANCES

Since the mid-twentieth century, a revolution in computer technology has made possible a quantum leap forward in human knowledge. The resulting explosion of scientific advances has had a dramatic impact on the field of forensic science by introducing a wide array of sophisticated techniques for analyzing evidence related to a crime. Procedures such as chromatography, spectrophotometry, and electrophoresis (all discussed in later chapters) allow the modern forensic scientist to determine with astounding accuracy the identity of a substance and to connect even tiny fragments of evidence to a particular person and place.

Undoubtedly the most significant modern advance in forensic science has been the discovery and refinement of DNA typing in the late twentieth and early twenty-first centuries. Sir Alec Jeffreys developed the first DNA profiling test in 1984, and two years later he applied it for the first time to solve a crime, identifying Colin Pitchfork as the murderer of two young English girls. The same case also marked the first time DNA profiling established the innocence of a criminal suspect. Made possible by scientific breakthroughs in the 1950s and 1960s, DNA typing offers law enforcement officials a powerful tool for establishing the precise identity of a suspect, even when only a small amount of physical evidence is available. Combined with the modern analytical tools mentioned earlier, DNA typing has revolutionized the practice of forensic science (see Figure 1-6).

Another significant recent development in forensics is the establishment of computerized databases to store information on physical evidence such as